11/14/97 U.S. PTO JC405

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PTO/SB/05 (8-96)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

NEW UTILITY PATENT APPLICATION TRANSMITTAL

(to be used for new applications only)

Attorney Docket Number	10733-215A
First Named Inventor	DANYLUK, Steven et al.
Total Pages in this Submission	

APPLICATION ELEMENTS

*Notice: Checklist items mentioned under **Application Elements** section construct a new utility patent application. Please refer to MPEP Sections 506, 601, (37CFR 1.77, 1.53, 35 USC 111, 112, 113) for detailed explanation regarding completeness of an original patent application.*

1. [x] Fee Transmittal Form (prescribed filing fee(s))
2. Specification
   - [x] Title of the Invention
   - [x] Cross References to Related Applications *(if applicable)*
   - [x] Statement Regarding Federally-sponsored Research/Development *(if applicable)*
   - [ ] Reference to Microfiche Appendix *(if applicable)*
   - [x] Background of the Invention
   - [x] Brief Summary of the Invention
   - [x] Brief Description of the Drawings *(if drawings filed)*
   - [x] Detailed Description
   - [x] Claim or Claims
   - [x] Abstract of the Disclosure
3. [x] Drawing(s) *(when necessary as prescribed by 35 USC 113)*
4. [ ] Executed Declaration
5. Genetic Sequence Submission *(if applicable, all must be included)*
   - [ ] Paper Copy
   - [ ] Computer Readable Copy
   - [ ] Statement Verifying Identical Paper and Computer Readable Copy

ACCOMPANYING APPLICATION PARTS

6. [x] Assignment Papers (copy from priority provisional applic.)
7. [ ] Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
8. [ ] Computer Program in Microfiche
9. [ ] English Translation Document *(if applicable)*
10. [x] Information Disclosure Statement/PTO-1449 [x] Copies of IDS Citations
11. [ ] Petition Checklist and Accompanying Petition
12. [ ] Preliminary Amendment
13. [ ] Proprietary Information
14. [x] Return Receipt Postcard
15. [x] Small Entity Statement
16. [ ] Additional Enclosures *(please identify below)*:

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm or Individual name	DEVEAU, COLTON & MARQUIS Laurence P. Colton, Reg. No. 33.371
Signature	Laurence P. Colton
Date	14 November 1997

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Application Number		Class		Independent Claims	
Date of Receipt	Application Type	GAU		Total Claims	
	Filing Date	Foreign Filing License?		Drawing Sheets	
	Small Entity	Foreign Address?		Special Handling?	

PTO/SB/17 (10-96)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

FEE TRANSMITTAL

TOTAL AMOUNT OF PAYMENT ($)

Complete if Known	
Application Number	
Filing Date	11 November 1997
First Named Inventor	DANYLUK, STEVEN et al.
Group Art Unit	
Examiner Name	
Attorney Docket Number	10733-215A

METHOD OF PAYMENT (check one)

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number: 04-0925

Deposit Account Name:

☒ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

☐ Charge the Issue Fee Set in 37 CFR 1.18 at the Mailing of the Notice of Allowance, 37 CFR 1.311(b)

2. ☒ Payment Enclosed: ☒ Check ☐ Money Order ☐ Other

FEE CALCULATION (fees effective 10/01/96)

1. FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	770	201	385	Utility filing fee	395.00
106	320	206	160	Design filing fee	
107	530	207	265	Plant filing fee	
108	770	208	385	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 395.00

2. CLAIMS

			Extra		Fee from below		Fee Paid
Total Claims	10	-20 =	0	X		=	0
Independent Claims	2	- 3 =	0	X		=	0
Multiple Dependent Claims				X		=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	22	203	11	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim
109	80	209	40	Reissue independent claims over original patent
110	22	210	11	Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 0

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,460	147	2,460	For filing a request for reexamination	
112	900*	112	900*	Requesting publication of SIR prior to Examiner action	
113	1,790*	113	1,790*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for response within first month	
116	390	216	195	Extension for response within second month	
117	930	217	465	Extension for response within third month	
118	1,470	218	735	Extension for response within fourth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,470	138	1,470	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,290	241	645	Petition to revive unintentionally abandoned application	
142	1,290	242	645	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	650	244	325	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	230	126	230	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	770	246	385	Filing a submission after final rejection (37 CFR 1.129(a))	
149	770	249	385	For each additional invention to be examined (37 CFR 1.129(b))	

Other fee (specify) ______

Other fee (specify) ______

SUBTOTAL (3) ($) 0

* Reduced by Basic Filing Fee Paid

SUBMITTED BY				Complete (if applicable)	
Typed or Printed Name	Laurence P. Colton			Reg. Number	33,371
Signature	Laurence P. Colton	Date	11/14/97	Deposit Account User ID	

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Patent
Docket No.: 10733-215A
Document No.: KRS01645.PTO

APPLICATION FOR LETTERS PATENT

UNITED STATES OF AMERICA

Be it known that we, Steven **Danyluk**, a citizen of the United States of America, residing at 3535 Grove Gate Lane, Atlanta, Georgia 30339; Anatoly **Zharin**, a citizen of Belarus, residing at Byelorussian PM Association, Platonova Str. 12, Minsk, Belarus 220832; Elmer **Zanoria**, a citizen of the United States of America, residing at 301 Briarcliff Avenue, Apartment N-2, Oak Ridge, Tennessee 37830; Lennox **Reid**, a citizen of the United States of America, residing at 2700 Woodland Park Drive, Apartment 204, Houston, Texas 77082; and Kenneth **Hamall**, a citizen of the United States of America, residing at 119 Arbor Gate, Peachtree City, Georgia 30269 have invented certain new and useful improvements in a

NON-VIBRATING CAPACITANCE PROBE FOR WEAR MONITORING

of which the following is a specification.

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1360 Peachtree St., N.E.
Atlanta, Georgia 30309-3214

NON-VIBRATING CAPACITANCE PROBE FOR WEAR MONITORING

STATEMENT OF RELATED APPLICATIONS

This application is based and claims priority on United States of America provisional patent application serial number 60/030,814, filed on November 14, 1996.

STATEMENT OF GOVERNMENT INTEREST

Part of the work for this invention was funded by the United States of America Office of Naval Research under contracts numbers N00014-95-1-0903 and N00014-94-1-1074. The government of the United States of America has certain rights to this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to non-contact sensors for monitoring surface variations of a component part, and more specifically relates to a non-vibrating capacitance probe which uses a variable capacitor to measure the contact potential difference between two surfaces, generally on the same component part, and thereby recognizes surface variations such as wear of an object subjected to, for example, a sliding contact.

2. Technical Field

Mechanical systems such as heat combustion engines have components that are dynamically in contact with another body. These components are subjected to cyclic motions that can involve impact loading, shear straining, plastic deformation, frictional heating and fatigue of subsurface regions. A combination of these mechanisms often leads to surface damage that impairs the performance of the component. In addition, the chemical interaction between the component surface and surrounding fluids also can accelerate surface degradation. Such problems, if unattended, can result in catastrophic malfunction of the machine and even compromise operational safety. In this regard, it is desirable to monitor the surface condition of a critical tribocomponent. The design of sensors to monitor the surface condition of the tribocomponents and the operation of machinery depends largely on the nature of tribological application.

A surface-monitoring method that exploits the spatial variation in the work function of a material is presented herein. The work function refers to an energy barrier to prevent the escape of electrons from the surface of the material. The work function is governed by the physio-chemical nature of the surface and also depends on the environmental conditions. From a tribological standpoint, the work function is a useful parameter for evaluating mechanical deformation features such as dislocation pile-ups and residual stresses. For example, it has been demonstrated that a metal subjected to different degrees of compressive stress exhibits a variation in the work function. *Craig P.P. and Radeka, V., "Stress Dependence of Contact Potential: The ac Kelvin Method," Rev. Sci. Instrum., Vol. 41, pp. 258-264, 1969.* The present invention is a non-vibrating capacitance probe as modified from that of the Kelvin-Zisman method, *Zisman, W. A., "A New Method of Measuring Contact Potential Differences in Metals," Sci. Instrum., Vol. 3, pp. 367-370, 1932*, that uses a variable capacitor to measure the contact potential difference (CPD) between two surfaces.

SUMMARY OF THE INVENTION

Briefly described, in a preferred form, the present invention monitors the surface variations, such as surface wear, of a component. The surface wear is measured by the spatial variation in the work function of the component. The work function refers to an energy barrier to prevent the escape of electrons from the surface of the component. The invention detects the surface charge of the surface of the component through temporal variation in the work function of the component.

The present invention generally comprises the novel combination of a means for supporting the component and a non-vibrating capacitance probe, and the use of the non-vibrating capacitance probe in this combination to carry out the wear monitoring function of this invention. The component and non-vibrating probe are located in close proximity to each other. The relative motion between the component and the non-vibrating probe, the distance between them, and the contact potential difference between them, all are monitored. The work function of the component is found by monitoring the current induced by contact potential difference in the non-vibrating probe and relating it to the known work function of the electrode in the probe.

The present invention is directed to a non-vibrating capacitance probe which may be used as a non-contact sensor for tribological wear. Specifically, the present invention is a device which detects surface charge through temporal variation in the work function of a material. An artificial spatial variation in the work function is imposed on a shaft surface by coating a segment along the shaft circumference with a metal paint wherein the paint is compositionally different than the shaft surface. As the shaft rotates, the reference electrode senses changing contact potential difference with the shaft surface, owing to compositional variation. Temporal variation in the contact potential difference induces a current through an electrical connection. This current is amplified and converted to a voltage signal by an electronic circuit with an operational amplifier. The magnitude of the signal decreases asymptotically with the electrode-shaft distance and increases linearly with the rotational frequency.

In one embodiment of the apparatus, the component to be monitored for surface variations either is a cylindrical shaft composed of the material to be monitored, or wear-tested, or is a cylindrical shaft coated with the material to be monitored, or wear-tested. The component is supported by roller bearings on both ends of the shaft, allowing rotation of the shaft along its axis. The shaft is rotated by a motor and the rotational speed of the shaft is monitored. A non-vibrating capacitance probe is mounted on an xyz-positioning system, and a monitor detects the spacing between the shaft surface and probe. A monitoring device interprets the current induced in the non-vibrating capacitance probe as a difference in work function between the component and the known work function of the reference electrode in the probe. The process of measuring the work function of the component comprises the creation of relative rotational motion between the component and the non-vibrating capacitance probe. The relative motion of the component and probe, and the distance between the component and probe also are monitored.

One application of the non-vibrating capacitance probe is for detecting surface wear of an object subjected to sliding contact. One technique is to apply a thin coating of a material on the sliding body that is compositionally different from the substrate. Partial removal of this coating due to sliding contact creates sites where the substrate material is exposed. Formation of these sites create lateral compositional variation, thus,

heterogeneity in the work function of the wear surface. This yields an induced-current pattern that is unique from that of the unworn surface coating.

Accordingly, it is a primary object of the present invention to provide an apparatus comprising a non-vibrating capacitance probe which can be used as a non-contact sensor for tribological wear.

It is another object of the present invention to provide an apparatus comprising a non-vibrating capacitance probe which can be miniaturized and installed in systems that have moving parts.

These and other objects, advantages, and features of the present invention will become apparent to those skilled in the art upon reading the following specification in conjunction with the accompanying drawing figures, in which like reference numerals designate like parts throughout the several views.

DESCRIPTION OF THE DRAWING FIGURES

Fig. 1 is a schematic of the Kelvin-Zisman method (prior art).

Fig. 2 is a graph of CPD variation measured by the present invention between the reference electrode and a rotating cylindrical surface composed of materials A and B.

Figs. 3(a) and 3(b) show the theoretical variation of dV/dt with time for different values of x.

Fig. 4 shows the theoretical maximum dV/dt plotted as a function of frequency.

Fig. 5 shows the experimental set-up for a preferred embodiment of the present invention.

Fig. 6 is a circuit diagram of the non-vibrating capacitance probe, according to one form of the present invention.

Figs. 7(a) and 7(b) show experimental samples of probe output signal for different values of x.

Fig. 8 shows the magnitude of maximum output plotted as a function of probe-sample distance.

Fig. 9 shows a linearized plot of maximum output as a function of probe distance.

Fig. 10 shows the magnitude of maximum output plotted as a function of rotational frequency.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Theoretical

The theoretical background detailed below provides a description of the Kelvin-Zisman method to monitor a surface probe, and demonstrates the operation of the probe on a rotating shaft.

Kelvin-Zisman Probe

Referring to Fig. 1, the Kelvin-Zisman technique is accomplished by creating a parallel plate dynamic or vibrating capacitor 10 by vibrating one plate, the reference electrode 12, relative to a second plate, the sample surface 14 of interest. The surface 14 corresponds to the component subject to wear or to having other surface variations. The vibration induces a current flow, i, which can be described in terms of the geometry of the capacitor 10 and difference in work function between the reference electrode 12 and surface 14. If the work function of the reference electrode 12, φ_{ref}, is known, then the changes in the work function of the surface 14, $\varphi_{desired}$, can be related to whatever experimental conditions are chosen. The general equation for the inducted current is

$$i = V(dC/dt) + C(dV/dt) \quad (1)$$

where V, the CPD voltage, is defined by

$$V = (\varphi_{ref} - \varphi_{desired})/e \quad (2)$$

and C, the capacitance, is expressed as

$$C = \varepsilon_r \varepsilon_o A/d \quad (3)$$

where e is the charge of an electron, ε_r is the relative dielectric constant, ε_o is the permitivity in free space, A is the area of the reference electrode, and d is the spacing between the surfaces.

A typical experimental condition involves a reference electrode that does not detect a varying $\varphi_{desired}$, thus, the term dV/dt in equation 1 is assumed to be zero. In most CPD-measurement studies, such a condition is implemented by having the vibrating reference electrode fixed in position on a particular site of the sample surface. The induced current is contributed solely by the change in the capacitance owing to the sinusoidal variation in d expressed as

$$d = d_o + d_1 \sin \varpi t \quad (4)$$

where d_o is the mean spacing, d_1 is the amplitude, ϖ is the angular frequency, and t is the time. Substituting equation 4 into equations 3 and 1 yields

$$i = -V\varepsilon_r\varepsilon_o A d_1 \cos\varpi t/(d_o + d_1 \sin\varpi t)^2 \quad (5)$$

The Kelvin-Zisman technique to measure V is to provide a compensating voltage, V_c, to the capacitor 10, shown in Fig. 1, so that i = 0. The dc voltage could be applied either externally or through a feedback circuit via a phase sensitive detector.

Inventive Embodiment

In preferred form, the present invention comprises a non-vibrating capacitance probe for surface wear monitoring. The probe of the present invention forms a capacitor 10 between a reference electrode 12 and a surface 14 of interest, as described by the Kelvin-Zisman technique above. However, the spacing between the two surfaces, the electrode 12 being the first surface and the surface 14 being the second surface, in the present invention is fixed. Instead of the variable capacitance, the current is induced by the temporal change in CPD. Therefore, in reference to equation 1, the formulation for the induced current is simplified to

$$i = C\,(dV/dt) \quad (6)$$

Varying the CPD with time can be achieved by imposing a lateral displacement between the reference electrode 12 and the sample surface 14 with a heterogeneous work function. A combination of equation 6 with equation 3, which yields

$$i = \varepsilon_r\varepsilon_o A(dV/dt)/d, \quad (7)$$

suggests that the magnitude of the induced current decreases asymptotically with the capacitor spacing, and increases with the area of the reference electrode and the rate of CPD change.

One embodiment of the present invention is the scanning of a cylinder 30 having a cylindrical surface 20 rotating along its longitudinal axis 22, as shown in Fig. 2. Using the geometry depicted in Fig. 2, along the circumference of the cylinder 30, part of the surface 20 consists of material A, and the rest of the surface 20 consists of material B; each material having a unique work function.

As the cylinder 30 rotates at a constant speed, the reference electrode 40 senses a contact potential difference with material A, CPD_{EA}, and another potential with material B, CPD_{EB}. Also assume that CPD_{EB} is zero. The variation in the CPD with time can be

described by a rectangular wave function V(t) with an amplitude CPD_{EA}, as shown in Fig. 2. The Fourier series of the function is

$$V(t) = V'x + V'/\Pi \{\Sigma[(\sin(2\Pi nx)/n)\cos(w\Pi fnt)] + [(1-\cos(w\Pi nx)/n)\sin(2\Pi fnt)]\} \quad (8)$$

wherein $V' = CPD_{EA} - CPD_{EB}$, in volts, f is the fundamental frequency which is equivalent to the rotational frequency, x is the ratio of the arc length of A to the circumference of the cylinder, and n = 1, 2, 3, ...∞. The derivative of this function is defined by

$$dV/dt = -2V'f \{\Sigma[(\sin(e\Pi nx)/n)\sin(2\Pi fnt)] + [(1 - \cos(2\Pi nx)/n)\cos(2\Pi fnt)]\} \quad (9)$$

For $CPD_{EB} \neq 0$, the derivative of V(t) is still identical to equation 9 where the dc component is eliminated.

Fig. 3 shows plots of equation 9 for x values of 0.013 and 0.3. For these calculations, V′=1, f=15 Hz, and n=1 to 10. Each cycle of the wave consists of two major peaks, one with positive, maximum, value, and the other with negative, minimum, value. These peaks define the boundaries of material A where there are sharp changes in the CPD. The gap between the peaks widens as the length fraction of A increases.

Equation 9 indicates that the magnitude of the peak depends on the fundamental frequency. This is illustrated in Fig. 4 that reveals a linear increase in maximum dV/dt from 10 to 20 Hz. For this plot, x is fixed at 0.013 and V′ and n are the same as for Fig. 3.

It should be noted that waves with smaller amplitude separate the major peaks as shown in Fig. 3. There should be a straight line (dV/dt=0) instead because of the absence of CPD variation between material boundaries. The appearance of minor waves between the large peaks is attributed to the limited number of harmonics included in the calculation. With the higher number of harmonics, the amplitude of these waves approaches zero.

Another embodiment of the present invention, as shown in Fig. 5, comprises an aluminum shaft 100 rotated by a stepper motor 110. Both ends of the shaft 100 are supported by roller bearings 112, 114. One end of the shaft 100 is connected to the motor spindle 116 with a coupling 118. Interfaced with the motor 110 is a control box

120 for regulating the rotational speed of the shaft 100. The entire mechanical assembly is mounted on a vibration-isolation table 130. The rotational frequency of the shaft 100 is monitored by a tachometer 140. In the described sets of experiments, the rotational frequency was set at 10, 15, 20, and 25 Hz, corresponding to 600, 900, 1200, and 1500 rpm. The experimental shaft 100 was about 432 mm in length and about 50.8 mm in diameter.

A non-vibrating capacitance probe 150 is mounted on an xyz positioning system 160 which is mechanically isolated from the above set-up. Stepper motors, not shown, control the lateral motion of the probe 150 along the longitudinal axis of the shaft 100 and the vertical position. The probe 150 is positioned such that a reference electrode 152 in the probe 150 is perpendicular to the shaft 100 surface. A separate positioning stage with a translational resolution of 0.01 mm is used to manually adjust the spacing between the shaft 100 and the reference electrode 152. Spacings ranging from 01. to 1.25 were used in experimentation.

Artificial variation in the work function was imposed on the sample shaft 100 surface by coating a segment along the shaft 100 circumference with a colloidal silver paint. Most of the tests were conducted for a silver strip 170 with an arc length x that was 1.3/100, or 0.013, of the circumferencial length of the shaft 100. One test was performed for a separate coating with a length x fraction of 0.3. The coating strips were approximately 14-μm thick and 5-mm wide for this experimentation.

The reference electrode 152 of the probe 150 was made of lead wire with a cross-sectional area of approximately 0.446 mm^2. Electrical connection between the sample shaft 100 and the common ground of the probe's 150 electronic circuit was maintained through a brush in contact with the shaft 100. The current induced by the time-varying CPD between the electrode 152 and rotating shaft 100 surface was converted to a voltage output, as shown in Fig. 6, via a high ohmic circuit with a gain factor of 3.9×10^9 V/amp. The operational amplifier in the circuit received a dc power of ±9 V. The voltage output of the amplifier was recorded by a data acquisition system 180 at a rate of 10 kHz.

Fig. 7a shows an example of signal output for the silver strip 170 with a length fraction of 0.013. The signal exhibits a series of large waves, separated by fluctuations with smaller amplitudes. This pattern is identical to that of the theoretical signal which is

calculated for a similar length fraction, shown in Fig. 3a. The time interval between the large waves corresponds to the rotational frequency of the shaft 100. The interval between the maximum and minimum peaks of each wave packet represents the traverse of the probe 150 along the arc length of the silver strip 170. As per Fig. 2, upon entry into the silver strip 170, the reference electrode 152 senses an abrupt shift in the contact potential difference from aluminum to silver. At this point, the rate of change in CPD, i.e., dV/dt, is maximum (equation 7). As the reference electrode 152 moves from silver to aluminum, it senses another sharp change in CPD but with a dV/dt of reverse polarity. In accordance with this model, the interval between the maximum and minimum points of the large peaks is longer for the silver strip 170 with a length fraction of 0.3, shown in Fig. 7b.

An interval of minor waves separates the large ones as shown in Fig. 7a. This interval could be the electrical signature of uncoated aluminum. The fluctuation could reflect microstructural variation in the aluminum surface that also gives rise to heterogeneity in the work function. The microstructural variation could be linked to the machining history of the shaft 100.

The amplitudes of both the maximum and minimum peaks of the major wave is influenced strongly by the rotational frequency of the shaft 100 and the capacitance spacing. As an example, a quantitative analysis of the maximum peak measured for a silver strip with a length fraction of 0.013 is presented. Fig. 8 shows that the magnitude of the maximum peak declines non-linearly from 2.8 to 0.9 V with probe distance. It should be noted that the curves in Fig. 8 have identical shape; however, they shift to higher voltages as the rotational frequency increases from 10 to 25 Hz.

A mathematical equation for each curve in Fig. 8 can be derived by linearization. This is done by plotting the natural logarithm of the maximum voltage (V_{max}) against that of the distance, and then calculating the slope (s) and y-intercept (y) through linear regression. Fig. 9 reveals that the fit (r^2) of the linearized curves ranges from 0.99 to 1.00. Such excellent r^2 values confirms the validity of the curve fitting technique being applied. Rearranging the linear equation

$$\ln(V_{max}) = [s \, x \ln(d)] + y \qquad (10)$$

yields an asymptotic expression for V_{max}

$$V_{max} = c/d^3 \qquad (11)$$

where $c=e^y$. Equation 11 takes into account the negative slope indicated by the linearized plots in Fig. 9. Table 1 shows the values of c and s for each rotational frequency.

TABLE 1

Frequency (Hz)	c	s
10	0.874	0.6
15	1.130	0.8
20	1.565	0.9
25	2.040	0.8

The empirical equation for V_{max} conforms with the predicted model for the induced current (equation 7). Both equations are asymptotic; however, the experimental values of s in equation 9 range from 0.6 to 0.9. Except for f=10 Hz, these values are slightly below 1, which is the predicted value. It should be noted that the probe signal is acquired through a current-to-voltage conversion circuit with a gain factor of 3.9×10^9 V/amp. Taking this and equation 7 into account, it is proposed that the numerator, c, in the empirical equation, represents a product of the induced current, conversion factor, dielectric constants and dV/dt. Among these parameters, dV/dt which increases linearly with the rotational frequency, shown in Fig. 4, is variable.

Fig. 10 shows that, at a constant d, the magnitude of the maximum peak increases linearly with the rotational frequency and the slope for each line increases with decreasing spacing distance.

Therefore, the applicability of the non-vibrating capacitance probe for detecting surface variation in the work function has been presented. This variation is reflected by the nature of the current induced by the changing contact potential difference between the reference electrode and the surface in question. The magnitude of the induced current which indicates the sensitivity of the probe, decreases asymptotically with distance between the probe and sample, and increases linearly with the rate of CPD change. These results are consistent with the theoretical model.

While the invention has been disclosed in its preferred forms, it will be apparent to those skilled in the art that many modifications, additions, and deletions can be made therein without departing from the spirit and scope of the invention and its equivalents as set forth in the following claims.

What is Claimed is:

1. An apparatus for monitoring surface variations on a component, said apparatus comprising:

    (a) a non-vibrating capacitance probe;

    (b) means for positioning said non-vibrating capacitance probe in proximity to the component; and

    (c) means for measuring the contact potential difference between the component and said non-vibrating capacitance probe.

2. An apparatus according to Claim 1, further comprising a means for measuring the relative motion between the component and said non-vibrating capacitance probe.

3. An apparatus according to Claim 2, further comprising means for regulating the relative motion between the component and said non-vibrating capacitance probe.

4. An apparatus according to Claim 1, further comprising means for measuring the spatial distance between the component and said non-vibrating capacitance probe.

5. An apparatus according to Claim 1, further comprising a means for supporting the component.

6. An apparatus according to Claim 5, wherein said means for positioning said non-vibrating capacitance probe in proximity to the component is fixed relative to said means for supporting the component.

7. An apparatus according to Claim 1, wherein said surface variation is surface wear.

8. A process for monitoring surface variations on a component, comprising the following steps:

(a) imparting relative motion between the component and a non-vibrating capacitance probe;

(b) monitoring the relative motion between the component and the non-vibrating capacitance probe; and

(c) monitoring the contact potential difference between the component and the non-vibrating capacitance probe.

9. A process according to Claim 8, further comprising the step of monitoring the distance between the said test surface and the non-vibrating capacitance probe.

10. A process according to Claim 9, wherein the surface variation is surface wear.

ABSTRACT

A non-vibrating capacitance probe for use as a non-contact sensor for tribological wear on a component. The device detects surface charge through temporal variation in the work function of a material. A reference electrode senses changing contact potential difference over the component surface, owing to compositional variation on the surface. Temporal variation in the contact potential difference induces a current through an electrical connection. This current is amplified and converted to a voltage signal by an electronic circuit with an operational amplifier.

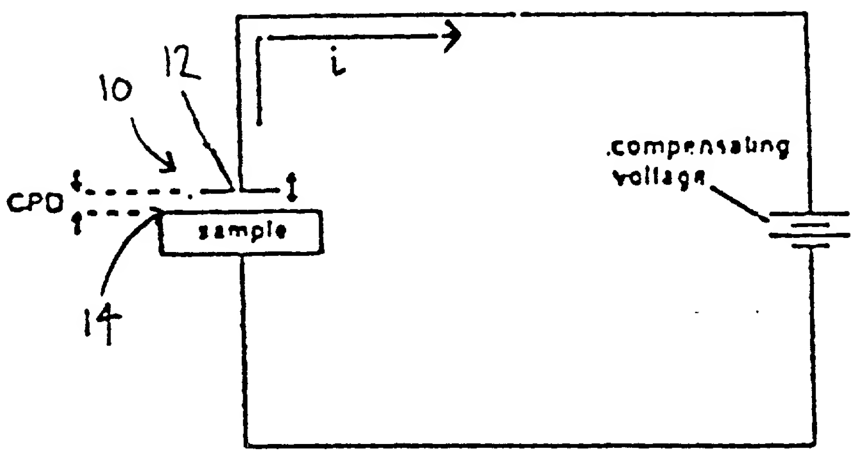


Fig. 1

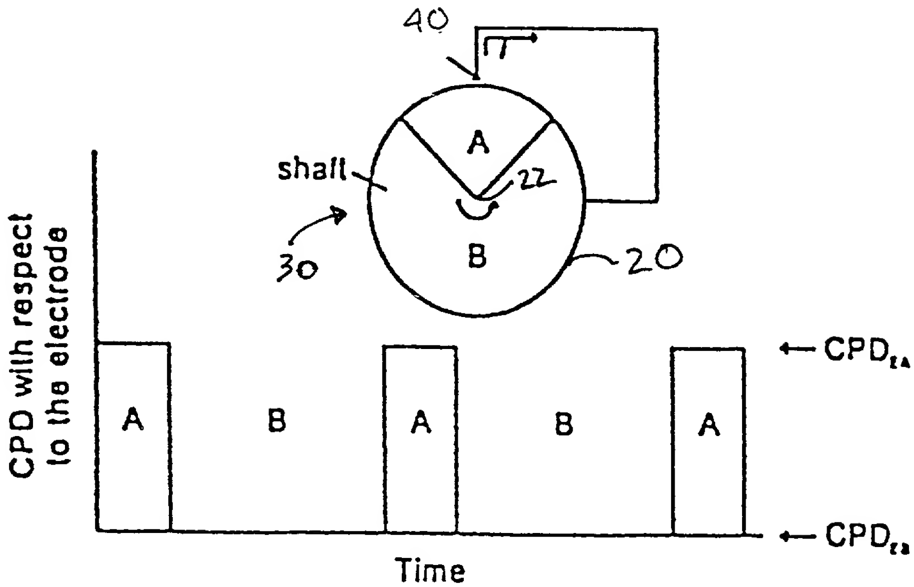

40
A
shaft
22
30
B
20
CPD with respect to the electrode
A
B
A
B
A
CPD2A
CPD2B
Time

Fig. 2

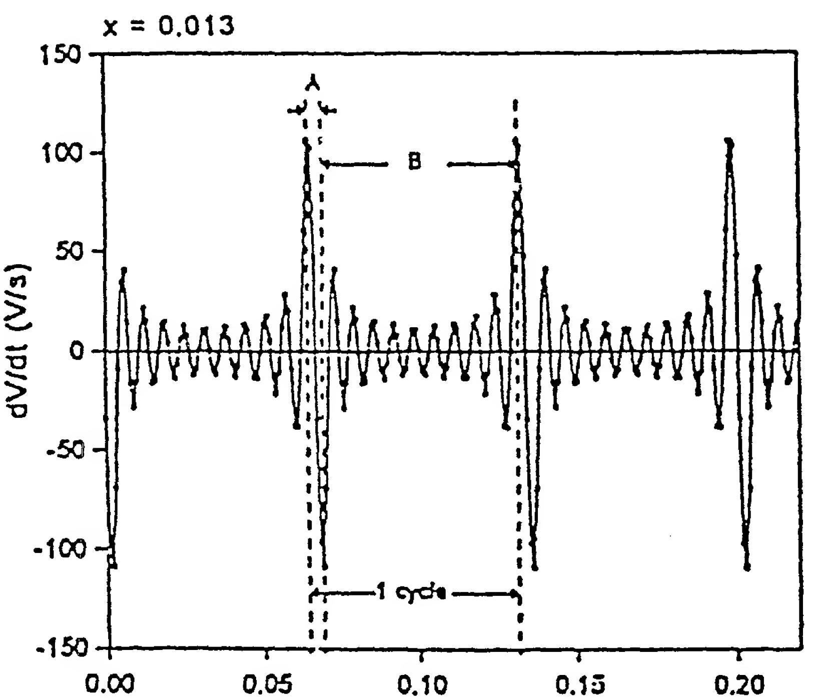

x = 0.013
150
100
50
0
-50
-100
-150
dV/dt (V/s)
A
B
1 cycle
0.00
0.05
0.10
0.15
0.20

Fig. 3a

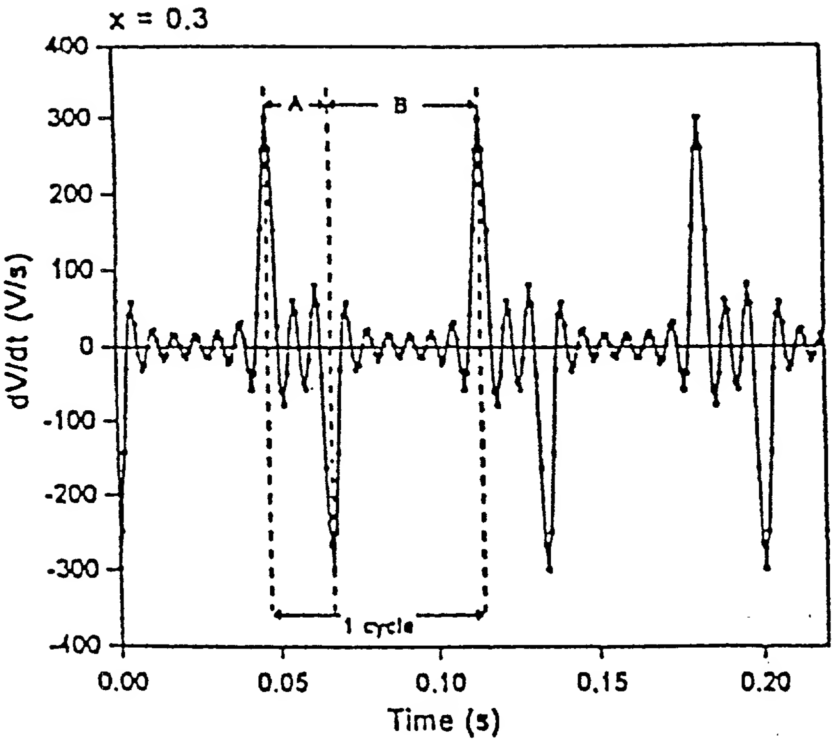

x = 0.3
A
B
1 cycle
400
300
200
100
0
-100
-200
-300
-400
dV/dt (V/s)
0.00
0.05
0.10
0.15
0.20
Time (s)

Fig. 3b

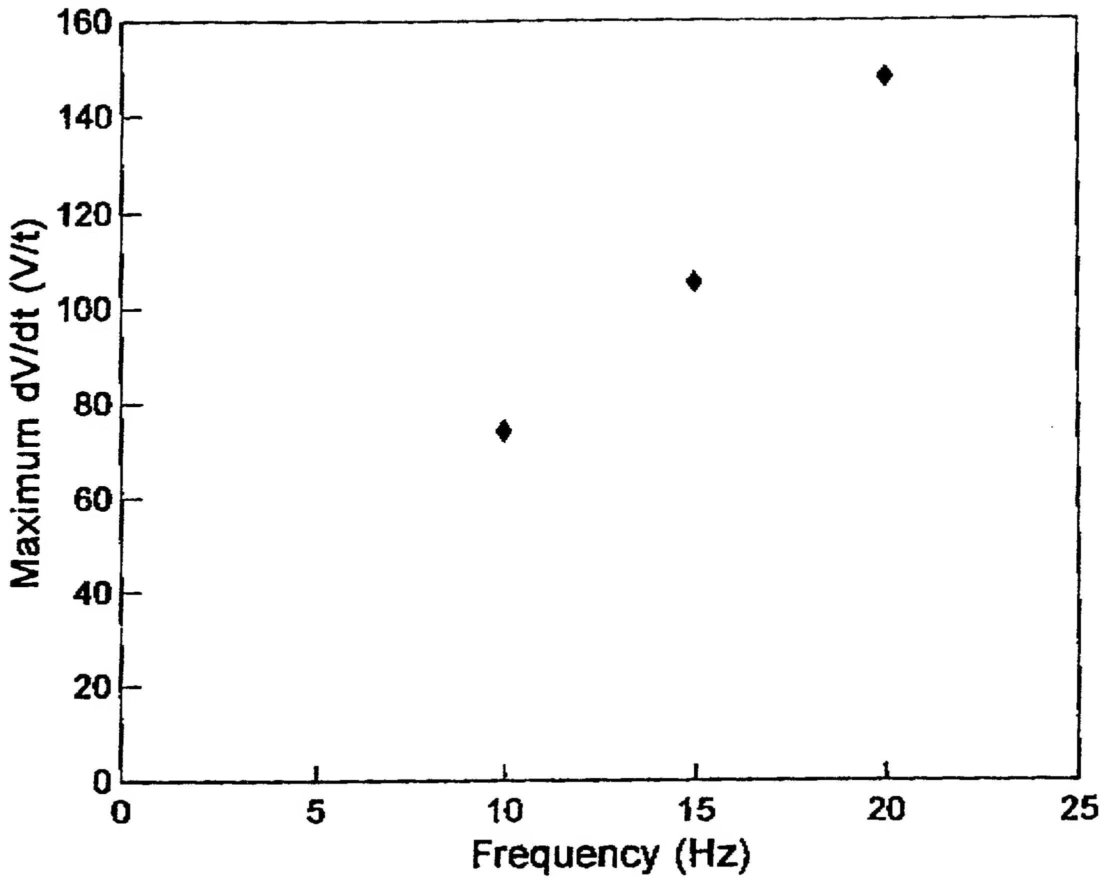
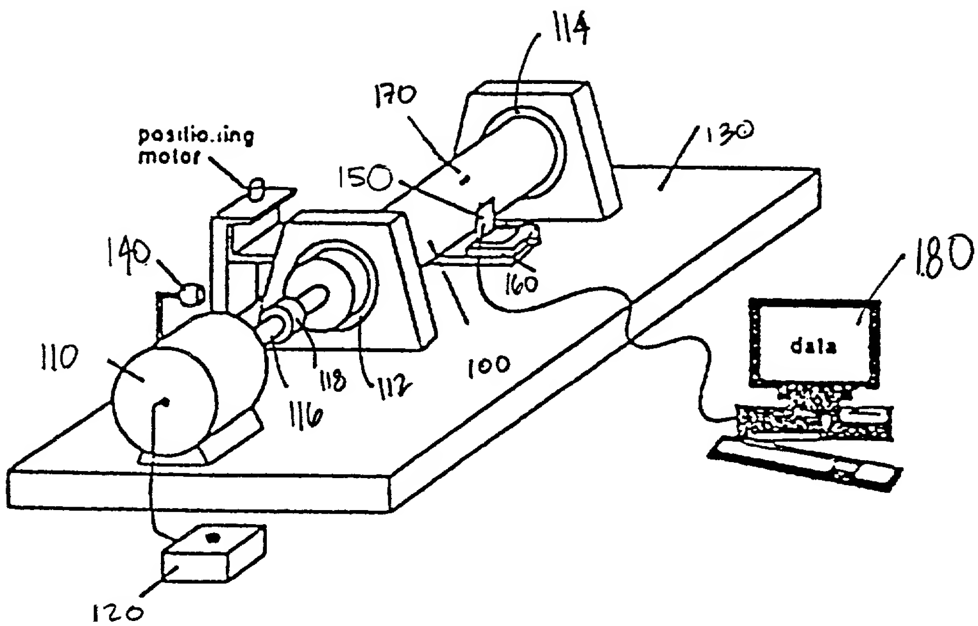

160
140
120
100
80
60
40
20
0
Maximum dV/dt (V/t)
0
5
10
15
20
25
Frequency (Hz)

Fig. 4



114
170
positio.ing
motor
130
150
140
160
180
data
110
118
112
100
116
120

Fig. 5

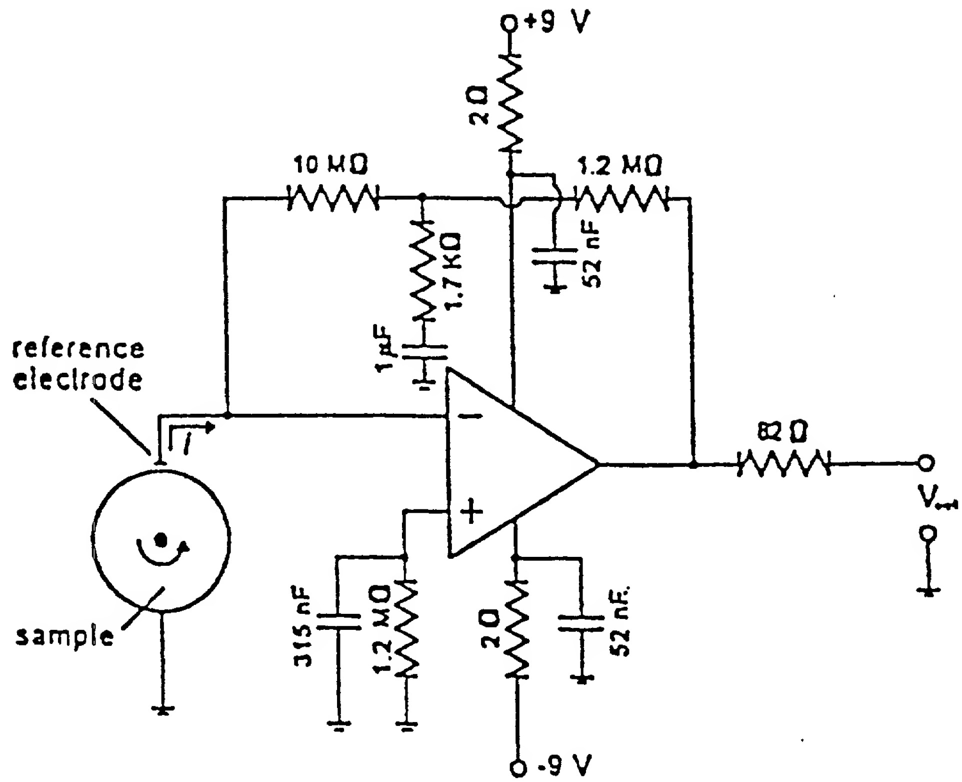

+9 V
2 Ω
10 MΩ
1.2 MΩ
52 nF
1.7 KΩ
1 µF
reference
electrode
I
sample
315 nF
1.2 MΩ
2 Ω
52 nF
-9 V
82 Ω

Fig. 6

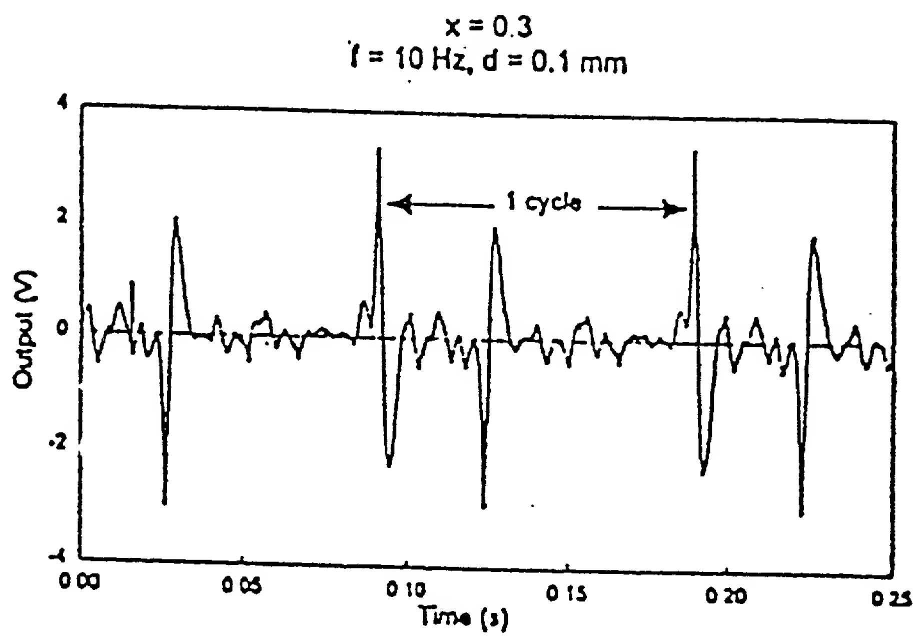

x = 0.3
f = 10 Hz, d = 0.1 mm
1 cycle
Output (V)
4
2
0
-2
-4
0.00
0.05
0.10
0.15
0.20
0.25
Time (s)

Fig. 7a

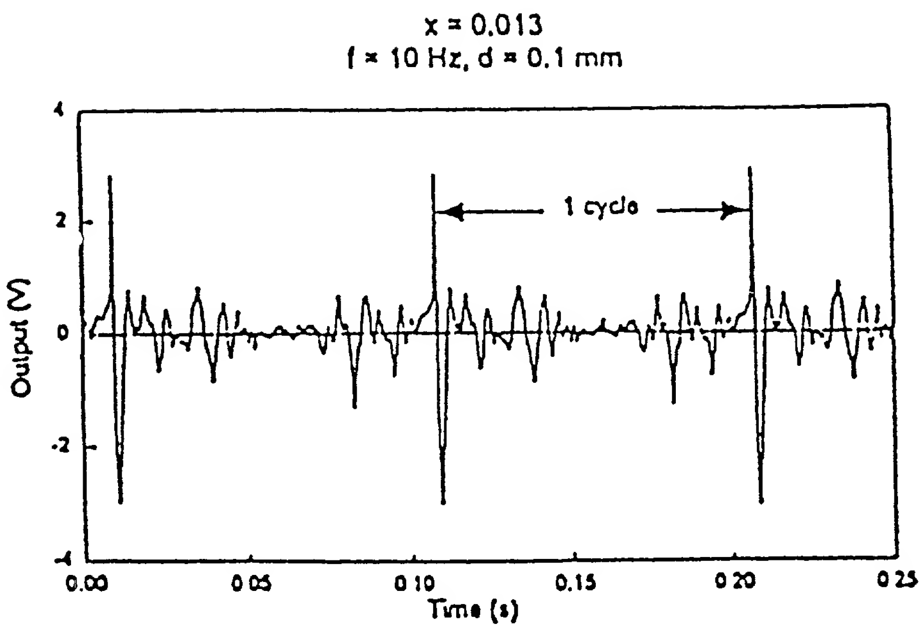

x = 0.013
f = 10 Hz, d = 0.1 mm
1 cycle
Output (V)
Time (s)
4
2
0
-2
-4
0.00
0.05
0.10
0.15
0.20
0.25

Fig. 7b

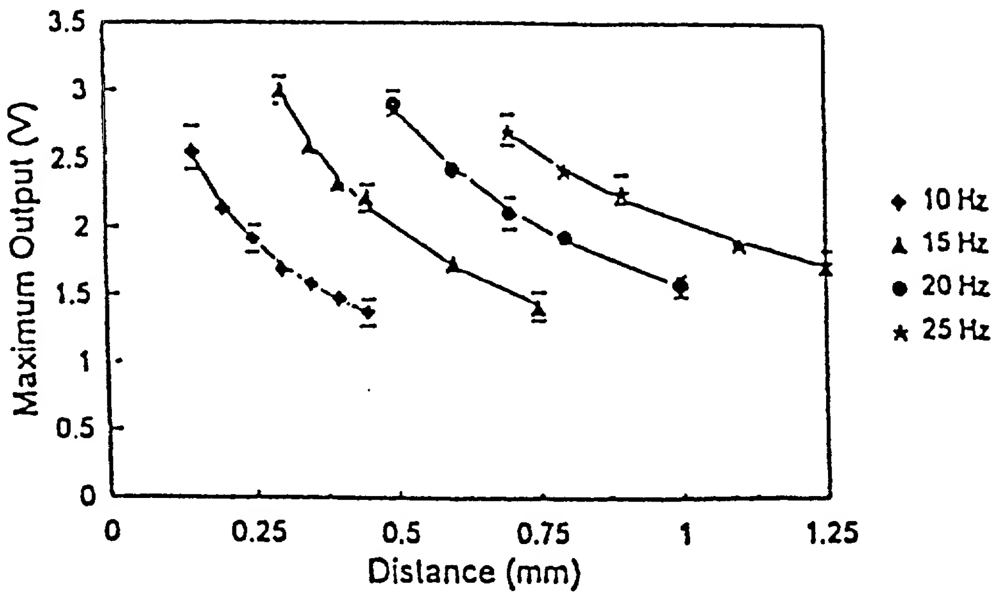

3.5
3
2.5
2
1.5
1
0.5
0
Maximum Output (V)
0
0.25
0.5
0.75
1
1.25
Distance (mm)
10 Hz
15 Hz
20 Hz
25 Hz

Fig. 8

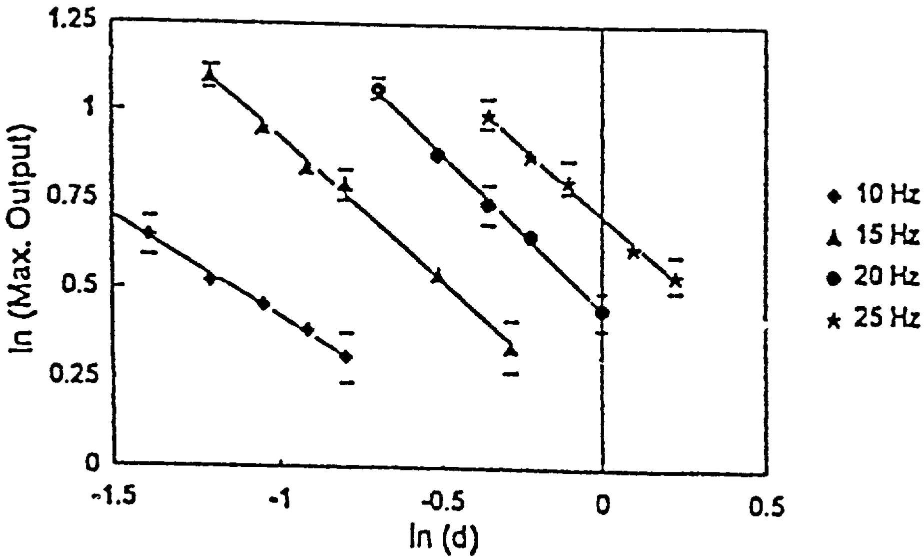

1.25
1
0.75
0.5
0.25
0
ln (Max. Output)
-1.5
-1
-0.5
0
0.5
ln (d)
10 Hz
15 Hz
20 Hz
25 Hz

Fig. 9

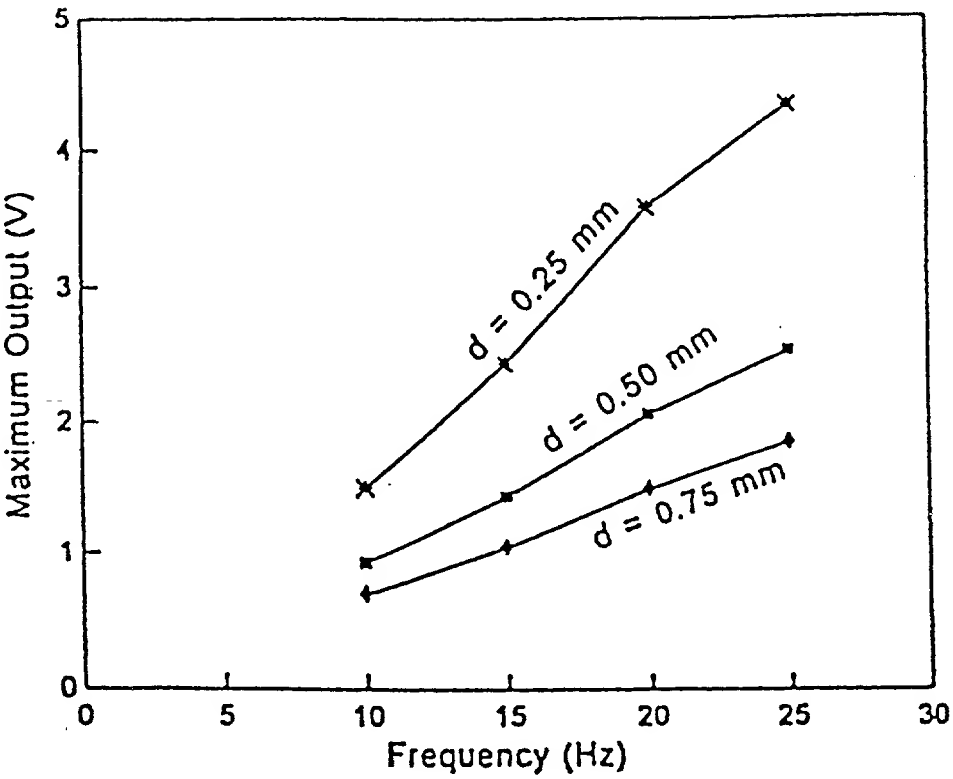

Maximum Output (V)
Frequency (Hz)
d = 0.25 mm
d = 0.50 mm
d = 0.75 mm
0
1
2
3
4
5
0
5
10
15
20
25
30

Fig. 10

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of **DANYLUK, Steven et al.**	)	
Serial No.:	)	Group Art Unit:
Filed:	)	Examiner:
For: **NON-VIBRATING CAPACITANCE PROBE FOR WEAR MONITORING**	)	

STATEMENT OF STATUS AS SMALL ENTITY

STATE OF GEORGIA)
) SS
COUNTY OF FULTON)

BARRY ROSENBERG, duly sworn, states that he is Director of Technology Licensing of GEORGIA TECH RESEARCH CORPORATION, empowered to act on behalf of GEORGIA TECH RESEARCH CORPORATION, and avers that GEORGIA TECH RESEARCH CORPORATION qualifies as a non-profit organization in that it is a non-profit scientific organization qualified under the non-profit organization statute of Georgia, and further avers that exclusive rights to the above-identified invention have been conveyed to and remain with GEORGIA TECH RESEARCH CORPORATION.

GEORGIA TECH RESEARCH CORPORATION

(L..S)
Barry Rosenberg, Director of Technology Licensing

Sworn to and subscribed before me this 1st day of May, 1997.

Notary Public
My Commission Expires: Notary Public, Gwinnett County, Georgia My Commission Expires November 28, 1997

c:winword\forms\techsmal.doc